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14) Facilities Visited: Indian National Science Academy, Delhi
Center for Advanced Technologies, Indore
Delhi University, Delhi
Tata Institute of Fundamental Research, Mumbai

15) Complete Report:

The primary purpose of the trip was to participate in the “Interaction Meeting on Linear Collider and Neutrino Physics”, held November 10-12, 2003 at the Indian National Science Academy in Delhi, India. This meeting was organized under the auspices of the Indian Department of Science and Technology (DST) and the Indo-US Science and Technology Forum. A delegation of 19 US physicists from universities and national laboratories attended the meeting. Fermilab assumed the lead on organizing the American side. This was natural choice because of our connections to the Indian high energy physics community through the D0 collaboration at Fermilab. On the Indian side, attendance was high, and the meeting attracted at most 75 physicists. Following the meeting, several members of the US delegation traveled to Indore for a visit/tour of the Center for Advanced Technologies (CAT) (November 13). Upon returning to Delhi a few of us met with scientists and the Vice-Chancellor at Delhi University (November 14). Many in the US team traveled to the Tata Institute for Fundamental Research (TIFR) in Mumbai. Further information on the meeting can be found at: http://www-td.fnal.gov/lc/meetings/delhi03.html.

Linear Collider Meeting

The first two days of the meeting in Delhi were devoted to discussion of the technology challenges and the physics research capabilities of an electron-positron linear collider (LC). Presentations given by the US side addressed the general world situation on linear collider international initiatives (M. Tigner), the technology challenges related to the two primary competing technologies (H. Padamsee and T. Himel), detector development issues (E. Fisk and S. Tkaczyk), and the physics research program (A. Kronfeld and J. Hewett). Presentations from the Indian side covered their technical capabilities and contributions to high energy physics program worldwide, including contributions to construction of detectors and accelerators.

Through the presentations and discussions the Indian physicists demonstrated a strong desire to participate in the linear collider accelerator R&D. This desire is strongly supported by the funding agencies (DST representatives were in attendance), and it appears to some degree to be driven from the top down. The Indian government is convinced that investment in technology development is in the interests of fostering their emerging economy. In this regard Indian motivations for participation in the linear collider R&D are more strongly coupled to ~~the~~ accelerator technology development than to the physics research program. We also saw in these presentations evidence that the Indian labs have strong capabilities in accelerator and detector technologies that are being applied to the operation and construction of synchrotron light sources (Indus-1 and Indus-2 projects), and a variety of low energy proton accelerators. They also have aspirations for constructing proton accelerators in the 10-100 KW range for use as spallation neutron sources. In addition, we heard about substantial contributions to construction of the LHC accelerator at CERN (superconducting correction coils are being constructed at CAT in Indore) and the CMS and Alice detectors. In conversations during the meeting on the possibility of collaboration the Indians seemed to feel that their relationship with CERN is something they would like to emulate with the US The relevant features of this relationship are on the one hand a single point of contact to the Indian community and on the other observer status within the CERN Council.

Details of the Linear Collider Presentations November 10 and 11, 2003

- **Opening Remarks – Prof. V.S. Ramamurthy**, the secretary of the Department of Science and Technology (DST). Prof. Ramamurthy talked about India's perspective on global partnerships in research. He noted that the Indo-US joint programs are not as large and inclusive as the separate scientific communities. He mentioned as an example the cooperation between the US NSF and the Indian Department of Science and Technology (DST). He remarked that the November meeting was stronger than the meeting that had been planned for March 2003. He mentioned some of the goals and accomplishments of the DST: establishment of a globally competitive infrastructure for education, he listed the chain of R&D labs across disciplines: food, nuclear technology, space technology, information technology, and the potential programs in biotechnology. He emphasized that science is global by character and that we all depend on the meeting of people to establish "meetings of minds". Global science partnerships are established at many levels: the scientist level, during meetings and conferences, in joint research projects, at joint facilities and laboratories that have resulted in: 50 bi-lateral agreements, ~25 years of collaborating at CERN with the most recent examples being the Photon Multiplicity Detector and the construction of equipment for the LHC. Presently, there are more than 200 Indian particle physicists and engineers participating in international projects and experiments. He concluded by saying it was up to all of us to define the future directions for research: the What, the Where and the Who.

- **Prof. Maury Tigner**, Cornell University, presented a talk on the Great Opportunity/Great Challenge that the linear Collider presents. He described the brief history of the Linear Collider discussions starting in 1965 in a meeting at Cornell, followed by ACFA endorsement of the project in1997 (http://ccwww.kek.jp/acfa/) and similar conclusions from ECFA in 2001 (http://committees.web.cern.ch/Committees/ECFA/wghep/wgreport213.pdf) and HEPAP in 2002 (http://doe-hep.hep.net/lrp_panel/index.html) and the Global Science Forum under the auspices of the OECD (Organization for Economic Co-operation and Development) (http://www.oecd.org/dataoecd/2/32/1944269.pdf). Prof. Tigner discussed the formation of the International Linear Collider Technical Review Committee whose membership has since been revealed. He reviewed the broad perspective of LC R&D at laboratories and universities around the globe and showed a chart that describes the present international framework for organizing work around the world that is being coordinated through the International Linear Collider Steering Committee. He described possible scenarios for evolution of the LC management structure and stressed the need for a global effort to design and build such a facility. A selection between these approaches for the main linac will be made in calendar 2004. For both cases the needed technology R&D is by now well documented and the channels for participation open to all who so desire.

We hope that Indian experimental particle physicists will take the lead in joining with Indian technology centers to pick out areas of interest in LC accelerator and detector R&D and make their interests known in the established venues.

- **Dr. A Mitra**, Department of Science and Technology, presented a talk on Indo-US Collaboration in Science. He described the long history of joint Indo-US projects dating back to 1950 that involved the Indian Department of Science and Technology and the US National Science Foundation. In all, there is a history of about 65 projects that range from biotechnology to space programs. Prof. Mitra was standing in for Dr. A. Kakodkar, Secretary of the Department of Atomic Energy, who was called away on urgent business on the first day of the meeting.

- **Dr. Andreas Kronfeld**, Fermilab, presented a perspective on the theoretical underpinning for the LC entitled: The State of Play in Particle Physics. He mentioned a book by Roger Penrose, "The Emperor's New Mind" (1989 – Oxford Univ. Press) in which Penrose ranks physical theories as Superb, Good or Speculative. In the same fashion, Andreas went through particle physics theory including the Standard Model, symmetry breaking, QCD, flavor physics, SUSY, the CKM matrix, quantum gravity, extra dimensions, etc. He speculated that on a time scale of a few years he expected the LC to make it possible for the above list to be classified and placed each item on his list under one of the categories.

- **Dr. Swapan Chattopadhyay**, Jefferson Lab, talked about Nano-beams, Proton Drivers and Free Electron Lasers. Dr. Chattopadhyay described many of the essential technical problems associated with the desired LC: Energy (rf technology) and Luminosity (small spot and high beam power). Small spot sizes require: low emittance damping rings, a final focus system, alignment and jitter tolerances, and beam-based alignment and feedback. Beam power (long bunch trains) results in high intensity short bunch length charge sources, long-range Wakefields, and the potential for radiation damage. Small spot size and high beam power require very high charge densities that in turn lead to damping ring instabilities and the need for beam collimation and machine protection. Dr. Chattopadhyay presented the very significant projects at the labs in the US that are attacking essentially all of these problems and he was careful to point out the need for more R&D so that the Indian scientists in attendance at the meeting could see the many opportunities for accelerator R&D.

- **Dr. Mangesh Karmarkar**, Center for Advanced Technology (CAT), discussed CAT's involvement in the CERN LHC project. In 1991, the DAE and CERN made an agreement to provide both manpower and components for the LHC. The work focused on superconducting magnet design, construction and cold testing, the LHC magnet protection system, multipole correction magnets and their protection, the accompanying cryogenic systems, accelerator magnet mechanical support and alignment, magnet test facilities and magnetic measurements, software development for accelerator controls' systems, the accelerator vacuum system and the beam dump system. CAT is supplying 1841 units of sextupole, octupole, and decapole correctors, their power supplies and quench protection systems, magnet installation positioning system, 4.2K test facility and LN2 tanks. Indian physicists and engineers are also involved in the LHC string #2 test.

- **Dr. Amit Roy**, NSC, presented a survey of Accelerator Development Plans in India pursued at BARC/TIFR-Mumbai, NSC-Delhi and CAT-Indore. Two tandem accelerators at Mumbai and Delhi were commissioned around 1990, which initiated heavy ion based experimental research programs. Superconducting boosters are under way for both Mumbai and Delhi tandems. At Mumbai, the booster will have seven accelerating modules, each containing four quarter wave resonators (QWR), to provide an energy gain of about 14 MeV/charge. The accelerating elements are independently phased 150 MHz, beta = 0.1 superconducting quarterwave resonators (QWR) made out of OFHC copper, plated with lead and housed in modular Helium cryostats. The fabrication of QWR's is being carried out at the Central Workshop, BARC and the lead plating is being done at the facility setup at TIFR. At Delhi, each superconducting booster module consists of four Niobium four gap resonators of 97 MHz to accelerate ions (up to mass ~ 100) to above the Coulomb barrier. These resonators were designed and developed in collaboration with Argonne National Laboratory. Resonators for two additional modules are being fabricated at Delhi. For this, a superconducting resonator fabrication facility is being set up. A cryogenics system, RF electronics, control system, beam transport system, and resonator fabrication facility have been installed at NSC.

  At the Center for Advanced Technology in Indore, the storage ring light source INDUS-1 has been running at 450 MeV. It has an injector system consisting of a microtron and a booster synchrotron. The desired current in the storage ring is 100 mA. A new storage INDUS-2 is being installed to reach an energy of 2.5 GeV and beam current of 300mA. The beam lifetime at 2.5 GeV is expected to be about 24 hours. Most components for INDUS-2 have been fabricated in Indian industry. The RF cavities were provided by ELETTTRA and the RF power by Russian industry. RF cavities will operate at a voltage of 1.5 MV and a frequency of about 500 MHz. There will be 6 beam lines for INDUS-2 with a critical wavelength of 3.8 Angstroms. One of the straight sections will be used for beam injection, two for RF cavities, and the remaining five for insertion devices including two wigglers.

  CAT has also taken up a major programme to develop a high current proton synchrotron for Accelerator-Driven Sub-critical Systems (ADSS). Design of 100 MeV CW proton linac is in progress using 350 MHz re-entrant shape Nb cavities. A facility for fabrication and testing cavities is under way. Under the CERN-India collaboration for the Large Hadron Collider, 250 superconducting corrector magnets, Precision Magnets Positioning Jacks, 60 Quench Projection Heater Power Supplies, 8 Quench Protection System Circuit Breakers were delivered to CERN.

- **Prof. Hassan Padamsee**, Cornell Univ. discussed the TESLA LC design and R&D that has taken place primarily on the development of 1.3 GHz superconducting (SC) RF cavities and associated hardware since 1990. The advantages of the SC design include larger dimensional tolerances in cavity manufacturing, less restrictive position and ground vibration requirements and more efficient use of wall plug electric power (~24%) than is anticipated with warm RF designs. The design for 500 GeV requires an accelerating gradient of 24 MV/m while 800 GeV requires 35 MV/m. To date, 50 RF cavity structures have been built and tested successfully that reach 24 MV/m. A total of 2300 nine-cell cryomodules are required in the TESLA design. Recently built and tested nine-cell structures have reached 35MV/m at the design Q of more than 5E09. These results are obtained for Nb cavities that have been electro-polished in the production process. In addition to the development of RF structures there have been significant achievements in the production and tests of RF couplers and tuners, RF power generation via klystrons, and in the development of short pulse beams in the TESLA Test Facilities. Prof. Padamsee noted that additional cavity development and testing is required and there are other projects in the TESLA collider design that require further R&D, such as the damping rings.

- **Prof. Tom Himel**, SLAC, discussed "Linear Collider Overview: status, challenges, R&D opportunities". There are two main challenges in the construction of a Linear Collider (LC): attaining the energy and the luminosity. There are two main technologies being pursued for the linac: 1.3 GHz superconducting cavities and 11.4 GHz copper cavities. Both programs have built test accelerators that demonstrated the technology at less than the design gradient and both have active programs to increase the maximum gradient. Both have achieved their design gradient in test structures but have not yet demonstrated this gradient in multiple structures in accelerator-like conditions. Large ongoing R&D programs are expected to achieve this in the near future.

  The design luminosity of the LC is 10^4 times that of the original LC at SLAC. This represents a considerable challenge. Multiple test facilities ranging from a prototype damping ring to a final focus test beam to major simulations of wakefields and tuning procedures have been used to show the feasibility of attaining this large improvement.

  While much R&D has been done, a lot remains to be done before the LC can be confidently built. A list of useful R&D projects has been compiled and is available on the web at www-conf.slac.stanford.edu/lcprojectlist/projectlist/intro.htm. A few items from this list are:

  1. Very fast extraction kickers needed for the damping ring of the superconducting design
  2. Detector background calculations needed for both designs
  3. Developing coating techniques to reduce the secondary electron yield of the damping ring beam pipe to ameliorate the electron cloud instability in both designs
  4. Design more reliable electro-magnets and power supplies
  5. Simulate beam dynamics in the damping rings and optimize the designs
  6. Develop the machine protection system, which must be much more sophisticated than ever before.

  There are many opportunities for R&D that will naturally lead into construction possibilities. Our Indian colleagues are encouraged to pick something they find interesting or challenging and start work on it.

- **Dr. Eugene Fisk**, Fermilab, discussed Physics Measurements at a Linear Collider. Dr. Fisk reviewed some of the physics measurements that are anticipated at a 500-1000 GeV linear collider. He showed what the Tevatron experiments can discover in the way of a low mass Higgs and possible SUSY states, and what we think the LHC will be able to discover, namely a Higgs in the mass range from 100 GeV to 1 TeV and some SUSY particles at large missing transverse energy or large effective multi-jet mass. He described detector requirements for an LC and illustrated what can be learned for three specific physics experiments: measurements of a neutral Higgs, measurements of Smuons and Selectrons, and longitudinal W/Z scattering where non-zero tri-linear and quartic gauge couplings will indicate new physics. Dr. Fisk cited studies that show the precise nature of LC measurements, compared to the LHC, and how such accurate Higgs mass and branching ratio measurements will be useful in determining what kind of Higgs has been observed. In the case of SUSY particle measurements, such as cited in the studies of Smuons and Selectrons the LHC will not have the precision obtained with polarized electron and positron beam linear collider data. The LC studies of longitudinal WW scattering show that the precision obtained with LC data will greatly exceed the precision of measurements made at the LHC. He emphasized the areas where detector R&D are needed and how Indian institutions could contribute to both technology and physics progress.

- **Prof. JoAnne Hewett**, SLAC, discussed the hierarchy problem, which notes, in general, the disparity between the scale of electroweak symmetry breaking and the scale(s) of unification and/or gravity. She highlighted the expectation that any resolution of the hierarchy problem would entail new physics at TeV energies, which could be probed by a future linear collider (LC). She noted that, in addition to supersymmetry, extra spatial dimensions provide a theoretical framework for solving the hierarchy problem. In either case, both the Large Hadron Collider (LHC) and the LC have a large discovery potential. The synergy between measurements at the two colliders can probe the geometry of the new space. If these ideas were to be verified experimentally, they would have a profound impact on our understanding of the universe.

- **Dr. Rohini M. Godbole**, Indian Institute of Science, Bangalore, split her presentation into two parts. In one, she discussed the supersymmetric resolution of the hierarchy problem. She compared and contrasted the information to be gleaned from LHC and LC. LHC would provide a wide variety of mass differences of supersymmetric particles, yielding a rough idea of the scale at which supersymmetry is broken. The measurement of the lightest supersymmetric particle would be at the 10% level; the LC would do much better, bringing the whole superpartner spectrum into better focus. Perhaps more importantly, the LC would provide measurements of couplings, which are necessary to demonstrate that the underlying dynamics are indeed supersymmetric. (Nearly any superpartner spectrum could be spoofed by non-supersymmetric physics at the TeV scale, such as states associated with extra dimensions.) In the other part of her talk, Dr. Godbole discussed Indian contributions to e+e- physics in general, and to LC studies in particular. Indian physicists have contributed significantly to phenomenological LC studies of supersymmetry and photon-photon collisions, which are documented in reports on LC physics from Asia, Europe, and the Americas. The work is carried out within the structure of the Indian LC Working Group (ILCWG). Details of their meetings and projects can be found at the web sites of the ILCWG,
http://hp0.cts.iisc.ernet.in/Meetings/LCWG/ and http://www.tifr.res.in/~lc/.

- **Dr. Saurabh D. Rindani**, Physical Research Laboratory, Ahmedabad, continued the discussion of LC physics. He discussed the opportunities to learn more about the top quark in e+e- collisions, and also non-e+e- collision options at the LC. The top quark, first discovered in the mid-90s at Fermilab, has the largest mass of all quarks. Its mass is close to the electroweak scale, so it is natural to ask if it plays a special role in electroweak symmetry breaking. Top-anti-top pair production in e+e- collisions is a clean and illuminating way to determine not only basic properties, such as the mass and width to high precision, but also to constrain the coupling of top quark to other particles. In this way, one can test if the top quark participates in interactions beyond the standard model. Further chances for discovery at a LC lie in other collision modes: gamma-gamma collisions, gamma-e collisions, and e-e- collisions. Indian phenomenologists have been active in studying what these collisions can offer. Gamma-gamma collisions are valuable for elucidating the Higgs sector in supersymmetric extensions of the standard model. Compton scattering (i.e., gamma-e -> gamma-e) and Moeller scattering (i.e., e-e- -> e-e-) at LC energies are sensitive to the exchange of new states, such as those in models with extra spatial dimensions.

- **Prof. Milind Purohit**, University of South Carolina, presented a talk on university contributions to the Linear Collider R&D. The popular perception is that accelerator components such as magnets and RF cavities are built by national labs and industry, while large detector components are built by national labs or large universities. In this context it seems futile for small universities to participate. However, in this talk we see that small universities can also contribute significantly to the Linear Collider effort.

  Three examples of such an effort are provided.

  The first is of the contributions made by a single individual, Prof. Achim Weidemann of the Univ. of South Carolina, who is contributing to experiment E-166 at SLAC, an experiment designed to create and measure positron polarization at the Linear Collider. Positron Polarization is essential for the Giga-Z project, and together with a polarized electron beam it provides an essential handle on both standard model as well as supersymmetric cross-sections. One can reduce or enhance cross-sections as needed to aid in the study of various signals. Of course, the polarization is essential for a precision study of the Weinberg angle. Experiment E-166 works by sending the SLAC electron beam through a helical undulator which creates polarized photons. These are then sent through a radiator, which creates polarized electron and positron beams. Finally, the positron beam polarization is measured. At this point, it is thought that 80% polarization can be achieved in excess of the 60% or so minimum polarization required for the linear collider. Our contribution to the experiment includes work on the data acquisition system, simulation and organization.

  The last two contributions described were work done by Prof. George Gollin of the Univ. of Illinois at Urbana-Champaign. The first of his projects involved setting up online diagnostics of RF cavities. During acceleration, these cavities may spark and otherwise malfunction. Using ultrasonic techniques, it should be possible to learn when and where such damage occurs. Prof. Gollin and his students and colleagues have set up a little experiment to investigate. Pursuant to their goals, they have already used two transducers to ping copper dowels to measure the speed of sound at ultrasonic frequencies. They have also successfully modeled the sonic response of the dowels as measured by the transducers. Similarly, Prof. Gollin and his students are involved in another project to model a Fourier series kicker for the TESLA damping ring.

  In summary, smaller universities can indeed contribute to the Linear Collider project; sometimes just a faculty member working with an undergraduate is all that is needed.

- **Dr. Jasbir Singh**, Panjab University, described India's involvement in CMS. The Indian institutes involved are: Panjab University. in Chandigarh, Delhi University, Bhabha Atomic Research Center (BARC) in Mumbai and the Tata Institute of Fundamental Research (TIFR) in Mumbai. Dr. Singh reviewed both hardware and software projects.

There are two major hardware projects: Outer Hadronic (HO) tile scintillators and a Si pixel-based endcap pre-shower detectors. The HO detectors consist of three radial layers of trays each containing 6 tiles with readout via WLS and clear fibers to PMTs. TIFR/Panjab produced 1872/864 tiles with embedded WLS and spliced clear fibers to make the HO detectors. Personnel from TIFR and Panjab University assembled the tiles in trays (2.51 m L X 0.35 m W) at TIFR. The detector trays were tested at TIFR and at CERN in a test beam.

The other hardware project was the design and manufacture of Si microstrip endcap pre-shower detector. The work was carried out by Delhi University and BARC. The Si detectors were manufactured at Bharat Electronics Limited (BEL) Bangalore, India. Their dimensions are 63mm (L) X 63mm (W) X 0.300mm (T). There was also involvement of the Indian groups with CERN in the development of the PACE3 test setup that was used to scan internal registers, check addressing firmware, calibrate internal DACs and current sources, measure noise performance, etc.

Software projects include the simulation of various physics monte carlo samples such as direct photon production (Delhi), top (Panjab), Higgs (TIFR), quark-lepton compositeness (TIFR), SUSY states (TIFR) and validation of GEANT4 using test beam data (TIFR and Panjab).

- **Dr. Sudeshna Banerjee**, Tata Institute of Fundamental Research, discussed India's participation in particle physics research at Fermila/D0. She gave a short history of the involvement of Panjab (1990), TIFR (1990), and Delhi (1994) Universities. All three of these institutions have carried significant responsibilities in D0 detector development projects and physics analysis efforts.

  Panjab University physicists worked on top quark studies, QCD, muon punch-through, cosmic ray muon scintillator veto R&D, micro-DST generation software, data analysis production and streaming and neural-network software development. Panjab also developed prototype muon pixel scintillation counters for Run II. Panjab thesis student research has focused on top quark studies (Bhatnagar-1997 & Kaur-2003).

  TIFR, with its expertise in cosmic rays, joined the muon detection effort in D0. They were one of two institutions that assembled cosmic ray veto counters that surround the top, sides, and most of the bottom of the D0 detector. They participated in commissioning the muon system and veto counters and have been involved in many phases of muon analysis topics. Other hardware topics they have done include pre-shower detector tests and muon trigger fanout card tests. TIFR software projects include HV control, fast monte-carlo for calorimeter simulation and Tau lepton identification. TIFR thesis research topics include: searches for supersymmetric particles (Shankar-1997; Parua-1998), searches for new physics (Gupta-1999) and searches for top/anti-top resonances (Jain-2003).

  Delhi University has been significantly involved in the development of calorimeter algorithms and associated jet/QCD physics topics. Delhi's thesis studies involve high Pt jets and jet algorithms (Bhattacharjee-1997).

  It is quite clear that Indian scientists on the Fermilab/D0 experiment have been very strong collaborators in both technology and physics.

International Collaboration on LC, Round table Discussion

At the conclusion of the Linear Collider part of the Interaction meeting there was a round table panel discussion on International Collaboration on Linear Collider and how India could contribute. Prof. B. C. Sinha, Director VECC and SINP, chaired the panel. Other members of the panel were Dr. Steve Holmes, Associate Director, Fermilab, Dr. H. E. Fisk, Senior Scientist, Fermilab and Dr. S. Chattopadhyay, Associate Director, Jefferson Lab from USA and Dr. V. C. Sahni, Director of CAT, Dr. D. D. Bhawalkar, ex-Director of CAT and Dr. D. Bhandari, from India. Several scientists present in the audience participated in the panel discussion.

Prof. Sinha led the panel discussions by stating India's strength in accelerator technology developments including RFQ, superconducting RF and cryo-technologies, and development of several accelerator components for CERN accelerators. He stated that the scientific strength of India has been in physics, detector developments and analyses of the data. Several Indian institutes and universities participate in research at laboratories around the world. Most of these collaborations have been on individual/group basis, scientists talking to other scientists and finding areas of common interest. There has been collaboration at a broader level where one Indian laboratory collaborates with a foreign laboratory. He also mentioned that CERN-India collaboration is a model where Indian institutes are collaborating as a group from India on both accelerator and detector development. He personally prefers collaboration of the first two types but he observed that with larger projects the latter kind of collaboration has strength. He informed about the commitments of the Indian accelerator and HEP physics community at the present stage and stated that Indian physicists and engineers are very busy with these. He stressed that our hands are not going to be full for a long time and so it is timely to have this discussion. He switched his focus from Linear Collider to Neutrino physics and informed the gathering about the INO project and India's commitment to build a neutrino laboratory for cosmic ray neutrino experiments and more importantly for training people.

Dr. Holmes presented his view on the Linear Collider and International collaboration. He described what it takes to form an international collaboration and how the Linear collider should be built with international collaboration. Each collaborating scientist, institute, funding agency should have a clear view of what needs to be achieved. He suggested that an effective collaboration is a bottoms-up collaboration, where scientific and engineering staff has interest in the project. But a bottoms-up collaboration does need a top down support. He asked the Indian scientists to decide on their own which part of accelerator R&D and Linear Collider they will like to join, but requested them to join at an early stage of R&D.

Dr. Bhawalkar talked about India's contribution to international accelerator projects. He mentioned India's collaboration with the US on the SSC project. Indian accelerator engineers were already working on the SSC when it was canceled. The Center for Advanced Technology, for which he was the founding director, participated in the LEP upgrade by building the corrector magnets. India is contributing to LHC by producing higher order correction magnets, quench protection system, software, magnet measurements, and commissioning. In his opinion the quality of contribution has improved and India as a whole should be looking for a challenging project. He said that the shortage of manpower is an issue but can be reduced by using the scientists from universities and technology institutes like the Indian Institute of Technology. India needs to tap into the scientific manpower, which is not participating in international projects. He stressed that India can contribute technically as well as by getting things manufactured in India at a much cheaper cost. He stressed that Indian industry can participate in a big way to reduce cost of accelerator components. In his presentation he also stressed that India should naturally participate in any major international collaboration if it directly benefits with this interaction by developing its local industry and research institutes.

After these initial presentations, the chair opened the floor for comments and discussion. Prof. Mani Tripathi, of UC Davis, asked the Indian High Energy Physicists to join the muon detector work for the Linear Collider project, ASIC design work for muon detector at Fermilab and tie it to the ASIC development laboratory in Chandigarh, India. This is one place he thought scientific exchange could take place quickly. Prof. Maury Tigner asked the Indian panel about the job situation in India and what are the prospects for young physicists. One panel member replied that jobs in fundamental science are as tight as anywhere, but people trained in these fields are finding jobs in research institutes, universities and in industry. Mr. Gurnam Singh, of CAT, raised the issue of trained people going to the west from India but not returning back and this creates a real problem where institutions are losing very talented people. Dr. Shekhar Mishra, of Fermilab, commented that this trend of brain drain is slowing down. Dr. Adam Para raised the issue of detector technology and INO. He stressed that the choice of detector technology should be physics driven and in his opinion a thorough physics study should be done before a detector choice is made.

After these comments from the floor, the chair asked Dr. Fisk, of Fermilab, on the panel for his comments. He pointed out that the main reason we want to collaborate with each other on any project is because it is good science and excellent technology. He stressed that the time is very critical for the international high energy physics community and that a future facility is needed to address some crucial physics issues in a timely manner. International collaboration requires agreement; we do have some agreement between India and US. On the national scene with whom to collaborate has political dimension too. India can collaborate and significantly contribute to a lot of detector R&D, construction and physics analyses. He mentioned the visa issue and said that it is being addressed at every level of the US government.

Dr. V. C. Sahni, Director of CAT said that it is a good idea to collaborate on a major project if it benefits both sides. His laboratory is interested in developing an electron accelerator and has seen similar proposals in the United States. He commented that this meeting is quite different than previous meetings on collaboration with India by any country, because the US visiting team has presented a whole list of R&D topics where one can collaborate. The dialog at this level at the early stage of the Linear Collider project is very positive from his view. He inquired if India can collaborate on other ongoing accelerator projects.

Dr. Brajesh Choudhary, of Fermilab, said that during the neutrino meeting presentation we would discuss Fermilab accelerator projects where India can collaborate. HEP physicists can participate in the accelerator activity along with their accelerator scientists and engineers from India. Dr. Shekhar Mishra commented that the Indian university and research institutes should work together to forge a collaboration of future experiments and accelerator development. This will be an excellent training ground for young students and staff. Prof. Naba Mondal of TIFR inquired how one could identify a project, which is “win-win” situation for both sides.

Dr. Bhandari, of VECC from the panel, talked about India's development of a superconducting cyclotron. He said India has several accelerator projects in its plan and we must get involved with the Linear Collider project, but the level of involvement should depend on India's own interest in accelerators. In the recent past, the quality of accelerators has improved and most of these accelerators have been designed and built by Indians. He suggested that these collaborations should be on an equal footing, i.e. on accelerator technology and relevant to India's own program. He expressed his concern that India may not be allowed to collaborate on these high technology projects like superconducting RF although Indian engineers have built their own accelerator with this technology.

Dr. Swapan Chattopadhyay, of Jlab, was last to comment from the panel. He thanked the participants and organizers for an interesting meeting and said that we are here to seek collaboration on science and technology on a large scale. We do not have a choice but to work together because these are long term and high cost projects. We need to get young people involved. He also asked India to join on current accelerator projects and pre Linear Collider accelerator R&D.

The meeting finished with a note that we should have a follow up meeting in the not too far future. The US side informed Indian scientists of the USLCW meeting in Canada in July 04 and requested them to participate.

<u>Private Discussion with DST and Laboratory Directors</u>

A meeting was held on Monday evening, November 10, to discuss more directly with DST and the laboratory directors possible modes of collaboration. Those present on the US side included M. Tiger/Cornell, S. Holmes/Fermilab, S. Mishra/Fermilab, S. Chattopadhyay /Jefferson Lab, and T. Himel/SLAC. Present on the Indian side were Prof. Ramamurthy, the secretary of the Department of Science and Technology, Dr. Shobho Bhattacharya, Director TIFR, Dr. Vinod C. Sahni, Director CAT, Dr. Praveer Asthana, Scientific Staff, DST, Dr. D. D. Bhawalkar, Ex-Director CAT, Dr. S. S. Kapoor, BARC, Prof. Bikash Sinha, Director SINP and VECC, and Dr. Amit Roy, Director NSC.

Before Dr. Ramamurthy arrived, there was a discussion of the visa problems from the Indian perspective. The US delegation expressed that it is well aware of the problems and that many organizations in the US are working on the issue. When Dr. Ramamurthy arrived, he put an end to this discussion by noting that this is a problem that was not solvable by those present in the room.

In the meeting, Dr. Ramamurthy pressed for a specific US proposal for India to assume responsibility for a piece of the LC program. We noted that construction of a linear collider was not imminent, but that a very substantial technology program was in the offerng over the next several years nonetheless. We resisted any attempt to assign specific tasks and suggested rather that we work with the Indian community in learning enough about the technology issues to identify areas that are of interest to them. We suggested the way to start was with person-to-person contacts rather than dictating from above. We further suggested that following a period of such communications those interested within the Indian community attend next summer's Linear Collider Workshop in Victoria, B.C. In association with that meeting we offered to organize a US-India session to discuss topics where the Indians might start contributing. Follow-un side trips to U.S. laboratories for further discussions and perhaps forging of alliances were also offered up.

Following the meeting, a written summary was prepared and iterated. The intention from the Indian side was to send this to the US laboratory directors as indicating what they felt came out of these discussions. An unofficial copy of this document is below.

Indo-US Science & Technology Collaboration on Accelerator R&D

A three day Indo-US interaction meeting on Linear Collider and Neutrino physics took place at the Indian National Science Academy, New Delhi on November 10-12, 2003, to explore the possibilities of collaboration between the two countries on accelerator and detector R&D leading to an international collaboration on the Linear Collider R&D. Extensive discussions took place in this meeting, both formal and informal, and it was felt by both sides that there are several areas in general accelerator R&D where the two countries can collaborate immediately even while the international picture of the Linear Collider is being formulated. After detailed deliberations, the two sides agreed on the following course of action in order to develop this collaboration further.

1. Linear Collider collaboration work to date around the world has been based on bilateral agreements involving individual scientists and their labs. Continuing on this mode can make the smoothest start for new collaborations between the two sides.

2. India and USA should define a framework to seek direct collaboration on matters of accelerator R&D and physics in areas of complementary interest with a long term focus on the Linear Collider.

3. A small working group, (4 members from each side) should be formed within a month to work out the details of this collaboration.

4. Existing DST-NSF programs and the Indo-US S&T forum, in particular, could be used to support the meetings of this working group and other collaborative activities.

Neutrino Meeting

The 'Neutrino Physics' section of the Indo-US meeting was held on Wednesday, November 12. The formal part of the session consisted of five presentations:

- **Dr. Adam Para**, Fermilab, presented an overview of the current issues in neutrino oscillation physics and outlined the NuMI experimental program: MINOS experiment and the proposed off-axis experiment. He stressed the unique match of the NUMI beam and the current requirements for oscillation experiments. He also suggested several possible areas for a collaborative contribution of Indian physicists to the Fermilab program.
- **Prof. Naba Mondal**, TIFR, presented the status and progress of detector R&D program dedicated to the construction of the India-based Neutrino Observatory (INO). This initiative (lead by Mondal) aims at the construction of 32 Kton magnetized detector at some underground location, to be selected, for further studies of atmospheric neutrinos. The current detector design calls for 6 cm thick steel plates as an absorber and glass Resistive

Plate Chambers as an active detector. The R&D effort on the RPC chambers is carried in close collaboration with Fermilab and Grand Sasso Laboratory.

- **Dr. Indumathi**, IMS, presented the status of the detector simulations, analysis and studies of the physics potential of the proposed INO facility. The primary goal of the experiment is observation of the oscillatory pattern and precise determination of the mass difference of neutrinos, especially in the case if the mass difference turns out to be smaller than the current central value.
- **Dr. Millind Diwan**, BNL, presented a proposed superbeam facility consisting of a very large water Cerenkov detector in a Homestake mine in conjunction with an upgraded AGS proton source and new neutrino beam line. A very long baseline and a megaton-class detector would enable detailed studies of the neutrino oscillation parameters, including CP violation with an on-axis neutrino beam, provided the backgrounds can be reduced to the desired level.
- **Dr. Douglas Michael**, Caltech, presented the Fermilab accelerator complex and its possible upgrades to increase the flux of protons delivered onto the neutrino target. He also described possible plans for major increase of the neutrino beam intensity via construction of a dedicated proton source, especially in its superconducting linac form. He did point out several areas where Indian contributions would be realistically possible and make a major impact on the Fermilab program.

In the following round table discussion, chaired by H. S. Mani, the US side was represented by Brajesh Choudhary, Sanjib Mishra and Adam Para, and the Indian side by G. Rajasekharan, N. Mondal, and M.N. Murthy. The discussion was focused on the proposed INO initiative, its physics potential, and its complementary and competitive values vis-à-vis other neutrino experiments. It seems to be quite clear that one of the main motivations for this program is establishment of an experimental facility in India to serve as a tool to educate young physicists in experimental techniques. It is hoped that such a facility can be also be used as a target for a possible future neutrino super beam although the physics justification can only be made for an electron neutrino beam from a neutrino factory. The INO initiative appears to have a strong support of the DST, although it appears that Indian physicist community is still rather small, but growing. Several ideas of a possible collaboration involving Indian participation in the NuMI program and advanced detector R&D were discussed, although their viability seems to be limited by a relatively small number of physicists available.

Visit to the Center for Advanced Technologies (CAT) in Indore

We traveled to Indore from Delhi on Wednesday evening, November 12. An onsite reception was arranged for that evening, hosted by the retired Director, Dr. Bhawalkar. The new Director, Dr. Sahni was also in attendance as were several staff members. The majority of us stayed overnight in the onsite guesthouse.

CAT focuses on technology, primarily accelerators and lasers. The laboratory was constructed 15 years ago with Dr. Bhawalkar as the founding director. The site is approximately 2000 acres, affording plenty of room for expansion. A self-contained (housing, school, medical facility) community exists on the site and approximately half the staff is resident. The total staff numbers about 1400; of these about 400 are scientists and engineers. This represents a very significant capability.

On Thursday, November 13, the day was initiated by a repeat of several of the Delhi presentations for the CAT staff. Attendance was very good. In the afternoon we toured the CAT facilities. Our itinerary included:

Indus I

The Indus I facility is a 450 MeV storage ring used to generate synchrotron radiation. Four beam lines are supported. The facility operates two shifts per day (from 07:00 to 23:00). The facility was in operation when we visited. We got the feeling that there is not a huge user community associated with this facility.

Indus II

The Indus II facility is currently under construction. When completed it will be a 2.5 GeV electron storage ring operating with a 300 mA current. Twenty-seven beam lines are being planned for the facility. The civil construction is essentially complete and the fabrication of accelerator components is well advanced. We saw a great deal of hardware in the form of magnets, power supplies, vacuum chambers, rf systems, and infrastructure in process and ready for installation. We were told that installation and commissioning would be completed over the next year. Based on what we saw this appears credible. Almost all the hardware we saw was fabricated in India, the primary exception being some of the rf equipment. To a cursory view the quality looked no different from what one would find in a comparable facility in the US, Europe, or Japan.

750 KeV Cocroft-Walton

We viewed a 750 KeV Cocroft-Walton accelerator that was being utilized for industrial processing of synthetic textiles.

LHC Corrector Magnets

CAT is responsible for the fabrication of roughly half the higher order corrector magnets for the LHC at CERN. The fabrication methodology was developed at CAT and transferred to Indian industry. We visited the test facility at which these magnets are measured before shipment to CERN. Cryogenic facilities at CAT allow testing at 4K, not at superfluid temperatures (2K). Follow-up measurements at 2K at CERN show good correlation with the higher temperature measurements at CAT.

0.1 MW Proton-facility

In the longer term, CAT is planning a 0.1 MW proton facility based on a linac injected synchrotron operating at 1 GeV $\times$ 100 μA. Planning is at the very early conceptual phase and we saw no associated hardware under development. There appear to be some natural connections between development of this facility and development of a proton driver in support of neutrino superbeams in the US

Following the tour, a closeout discussion was held between the US visitors and the lab senior staff. The focus of the discussion was on the need to keep in communication as a means to explore potential areas of mutual interest or collaboration on LC and proton facilities. The

US group encouraged the CAT people to make individual contacts with US counterparts as their interests dictated, and suggested a follow-up get together in the summer of 2004.

At CAT, we also discussed a possibility of exchange of scientific staff between the two countries. We think this is a way to develop collaboration. There are several possibilities, for example CAT scientists participating in SPEAR3 commissioning to gain valuable experience to commission INDUS-II. We also discussed the possibility of getting the Indian universities students to participate in accelerator R&D through CAT at the US laboratories. This will help increase the number of scientists trained in accelerators.

One area of possible collaboration between Fermilab and CAT is the superconducting proton Linac. Dr. Sahni asked his staff to send a short list of the research interests of his staff to Shekhar Mishra. This could be used to find mutual areas of interest.

Visit to University of Delhi on Nov 14th:

Gene Fisk, Steve Holmes, Shekhar Mishra and Brajesh Choudhary, visited the experimental high energy physics group at University of Delhi. They met the PI of the group Prof. R. K. Shivpuri and discussed the ongoing collaboration on the D0 collider experiment between the Delhi group and Fermilab. Possible collaboration on the linear collider between the University of Delhi and Fermilab was also discussed. Dr. Fisk talked to several graduate students and postdocs about their involvement in the CMS hardware, software, and physics projects.

Later, physicists from Fermilab with Prof. Shivpuri met Prof. Deepak Nayyar, Vice-Chancellor of the University of Delhi. Vice-Chancellor of an Indian university is equivalent to the President of an US university. Prof. Nayyar is an economist. The delegation appraised Prof. Nayyar of its mission in Delhi, the important contribution that the University of Delhi has made at Fermilab over the last 15 years and the possibility of collaboration between the University of Delhi and Fermilab on the Linear Collider project. The Vice-Chancellor hoped that the Delhi-Fermilab collaboration will get further strengthened under the leadership of Prof. Shivpuri.

Visit to Tata Institue of Fundamental Research, Mumbai. Nov 16-18, 2003.

A subset of the US visiting team traveled to the Tata Institute of Fundamental Research (TIFR), Mumbai on November 16th 2003. We met the chairman of the High Energy Physics, Prof. Naba Mondal and his wife for dinner and had an informal discussion about TIFR research and the Indian Neutrino Observatory (INO) proposal. Prof. Mondal is the spokesperson of INO.

On the morning of the17th we visited TIFR and met the staff scientists. We saw a movie on the TIFR research activities. TIFR is a basic science research institute performing research in Biology, Chemistry, Computer Science, Mathematics and Physics. In physics the TIFR scientists participate in the following areas of research: Astronomy, Astrophysics, Condensed Matter and Material Science, High Energy Physics, Nuclear and Atomic Physics and Theoretical. Physics. TIFR physicists participate in research at National Center for Radio Astrophysics, Pune; High Energy Gamma Ray Observatory, Pachmarhi; Cosmic Ray Laboratory, Ooty; Gravitation Laboratory, Gauribidanur and Balloon Facility, Hyderabad.

The TIFR high-energy physics group is participating in experimental research at several major international laboratories including L3 and CMS at CERN, BELLE at KEK and D0 at Fermilab. The TIFR high energy physics group has 17 Academic Members, 12 Research Scholars, 35 scientific staff and 26 technical staff. The group also has access to a pool of staff in the machine shops.

After the film, we got a short tour to the machine shops, CMM, scintillator cutting machine. These shops are well equipped and were at the level of Fermilab machine shops. This tour was followed by tea and a meeting with the TIFR staff. The TIFR director, Prof. Subho Bhattacharya told the visiting team his view on collaboration. He stressed the need of collaboration on mutual benefit projects. There are several accelerator projects in India that have common technology with US accelerator proposals. He also talked about possible collaboration on neutrino physics. Prof. Mondal stated that he is looking into the possible area of collaboration on detector R&D. Fermilab's Off-Axis neutrino proposal and INO have RPCs as one of the detectors of choice. It is possible that the two laboratories can collaborate on it. There was some discussion on possible international collaboration on INO. At present INO is an Indian effort. India seems to be very serious about INO.

After this meeting, we visited the 14 MeV Pelletron accelerator and Linac facility. These facilities are designed and built by TIFR/BARC and are used for Nuclear Physics Research. The end of the Linac is superconducting. Similar to CAT, local industries were involved in construction of this machine. We also visited the RPC R&D facility. TIFR has been successful in building a small working prototype. Neutrino physicists present were impressed with the facility and results.

After lunch, we were invited to meet Dr. Anil Kakodkar, Secretary, Department of Atomic Energy of India. His department funds the basic science research at all the accelerator based laboratories in India including CAT and TIFR. All members of US team went to his office with Prof. Naba Mondal of TIFR. Dr. Vinod Sahni, Director of CAT, joined us. Dr. Kakodkar gave us a brief outline of his department. His department has a broad spectrum of research with the main mission being Nuclear Power. The department also funds major basic research laboratories and construction of large facilities. He stressed that the research in physics and technology development is complementary. He discussed the CERN and Fermilab collaboration. He informed us that India has been given an observer status at CERN and has been taking a serious interest in the Computing Grid. India will be a Tier-II laboratory for the CERN Grid. He told the group that he has no problem working and collaborating with USA and things are improving between the two countries. He informed us that India will be doing a considerable amount of accelerator R&D for its own domestic interest and also just to be able to do these things. His department will be happy to participate in the Linear Collider and will strongly support it. He will like to take a programmatic view of this collaboration and sees a need of scientific and accelerator collaboration at a high level. He sees that the Indian industry will be involved in these developments because industry based accelerator work has a lot of growth potential in India.

Gene Fisk of Fermilab summarized the Delhi meeting. He went over the agenda of the meeting, described the talks in short and summary of the director's meeting. Shekhar Mishra described the Linear Collider Project, warm and cold technologies, International committee, technology decision in 04, etc. We also informed him that it is expected that the Technical Design Report R&D will start for one technology after the technology decision next year. It is important that India collaborates and contributes to this effort from the very beginning.

There is also a possibility of an Engineering Test Facility, a 1% demonstration machine of the selected technology. We also discussed the possibility of accelerator collaboration in the pre Linear Collider era.

Similar to Prof. Ramamurthy at the Delhi meeting, Dr. Kakodar also described the path of where India can collaborate. We informed him that there is a considerable amount of accelerator R&D and Indian scientists need to find areas of their interest and collaborate. Dr. Sahni pressed hard for specific area of collaboration. Since he had heard our presentation in Delhi and CAT, it appeared that India had found an area of mutual interest for CAT and Fermilab, i.e. the Linac based proton driver. Much of the accelerator R&D in India and US has common elements. Again the scientific personnel exchange between the two countries was discussed to reduce the effect of a shortage of trained manpower. We discussed several places where this could be helpful to both counties like Run-II, Spear-3 and Indus-II. We urged the Indian side to get universities involved with their national laboratories. Dr. Kakodkar likes this considerably. He stressed that such a plan is in the works and it will be an excellent idea that Indian universities and laboratories join together in training students in India and abroad. He talked about a pilot university program for targeted areas.

Adam Para and others described the possibility of collaboration on neutrino physics.

Shekhar Mishra informed him of the Vancouver meeting of the American Linear Collider Working Group and requested Indian participation.

The meeting concluded with the remark that we should continue to discuss how and in which areas to collaborate.

Accelerator Meeting at TIFR 18th Nov. 2003

The meeting at TIFR was extended by one day to have presentations by accelerator scientists. TIFR and BARC scientists work together on future accelerator development. They have a plan to develop a 1 GeV proton Linac. The Linac is being constructed in three parts, 1) 20 MeV Injector, 2) 100 MeV room temperature Linac, and 3) 1 GeV superconducting Linac. The design goal of the Linac is 10-30 mAmps. The described design is again very similar to Fermilab Linac based Proton Driver proposal. The group has secured funding for the 20 MeV injector. The injector has an ion source, RFQ, DTL and Beam Dump. The ion source is 2.45 GHz, 50 KeV, 60 mAmps designed and built by the group. They have designed a low energy beam transport to RFQ and RFQ. They discussed the space charge effect, cooling of the cavity and frequency shift issues. They will be building their own RFQ. The main reason to build their own is to develop local technical expertise. The group requested if US accelerator scientists could help in a technical review of the proposal and design.

Eugene Fisk of Fermilab met with TIFR physicists on the D0 experiment to discuss their research progress and plans associated Top and New Phenomena physics topics and of possible collaboration on linear collider detector R&D.

Summary and General Impressions

Much of the impetus for this meeting came from the Indian policy makers. It appears that the Indian government is convinced that investment in technology development is in the interests of fostering their emerging economy. In this regard, Indian motivations for participation in the linear collider R&D are more strongly coupled to the accelerator technology development rather than to the physics research program, which comes later. In this regard, there appears to be a slight disconnect in interest of the accelerator physicists and the experimental high energy physicists, who were more interested in neutrino physics experiments than in linear collider studies. There are a number of strong theoretical physics groups in India working on Linear Collider studies. High-energy physics experimentalists are joining them. It appears that the experimentalists have too many commitments at Fermilab, CERN, BNL and KEK to see their way clear to collaborate strongly on detector R&D at this time, but they say they are committed to join the detector project at an appropriate future date.

The Indian laboratories have strong capabilities in accelerator and detector technology that are being applied to construction of the LHC (superconducting correction coils are being constructed at CAT in Indore), to construction of the CMS and ALICE detectors at CERN, and to the construction/operations of synchrotron light facilities in India. They are in process of developing several small (1 GeV) accelerators for electron and proton beams. These accelerators have several elements common to US accelerator proposals. Nearly all the hardware that has been and is being assembled is supported via Indian industry, some of it as a direct result of technology transfer from the government sponsored laboratories. These capabilities could be brought to bear effectively on many LC R&D topics. Most of this capability is centered in the DAE supported laboratories. Real collaboration will require some sort of DOE(USA)/DAE(India) rapprochement.

The laboratories (at least CAT, which we visited) seem to be strongly focused on technology development, much more so than on basic research. The TIFR is more focused on basic research and high energy physics experiments, although they are also collaborating with other laboratories to build a 1 GeV proton accelerator with superconducting RF technology.

There is strong support within the government and laboratories to initiate collaboration with the US on linear collider R&D. It appears that this is based on past experience that collaborating with the US is easier than with Japan. (We did not explore the Japanese-India relation, but were nonetheless cognizant in our conversation.) Difficulties in securing visas for scientific visits to the US loom as the major concern the Indian community has regarding collaborating on the linear collider R&D. We received lots of remarks about the visa issue.

16) Cost of Trip: $4,498.50

Attachment(s)

U.S. Participants

Fermilab
- Brajesh Choudhary
- Gene Fisk
- Steve Holmes
- Andreas Kronfeld
- Shekhar Mishra
- Adam Para
- Slawomir Tkaczyk

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- Hasan Padamsee
- Maury Tigner

SLAC
- Vinod Bharadwaj
- Joanne Hewett
- Tom Himel

BNL
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Jefferson Lab
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University of South Carolina
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